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REPORT ON AN ORIGINAL FORM OF SULPHUR BURNER FOR DISINFECTION.

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The apparatus herein described has seemed, under experimental conditions, to satisfy the requirements it was designed to meet, namely, to put into a confined body of air a maximum concentration of sulphur dioxide from the minimum of sulphur in the minimum of time and with the minimum of labor and complications and the simplest and cheapest apparatus possible; and under a considerable variety of tests it has shown its decided superiority in general and in most particulars over the forms of apparatus now in common use.

This apparatus in its most approved form consists essentially of a double stack of long, narrow, flat, rectangular sheet-iron pans or shelves to contain the burning sulphur, arranged in the form of an inverted V. Each half of the double stack leans from the perpendicular at an angle of 60° , more or less (the individual pans being almost horizontal), in order to induce a strong current of air, flame, and burnt gases. Each pan in the stack, except the lowest, is heated by the flame of the one below it, whereby the combustion is made much more rapid and certain.

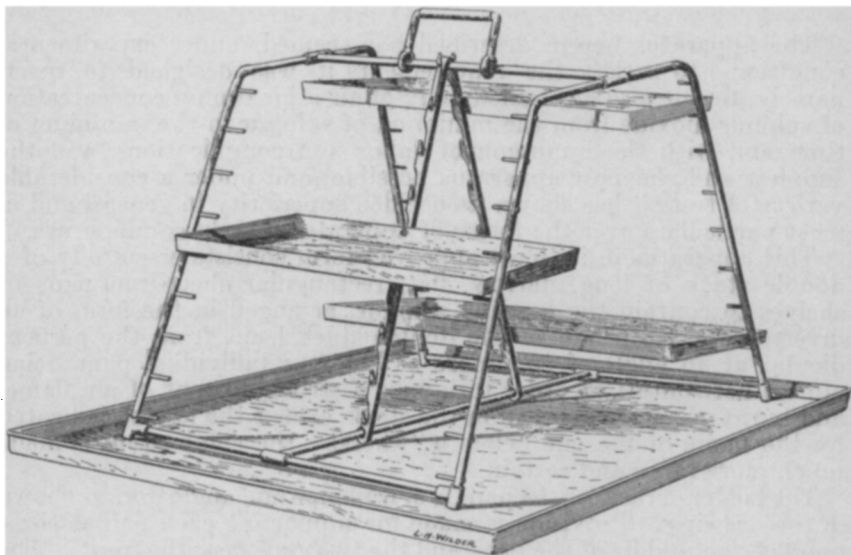
The holder or rack for the pans is of iron pipe and angle iron, as shown in the drawing. Provision is made for supporting each pan at three points—the middle of the back and the two ends near the front. The front points of support of the pans are along the four legs of the rack; the back points along the inverted V-shaped angle-iron brace in the center. The pans, trays, or shelves are of thin galvanized iron (No. 24 gauge has been found satisfactory), with sides and ends somewhat sloping to permit of nesting. The back side of each pan is somewhat deeper than the front and ends, and is perforated to accommodate the hook that forms the back support of the pan. The bottom of the pan slopes slightly downward to the back edge. There is also provided a large, flat, square safety pan for the burner to stand in, large enough in area and in capacity to catch and hold any or all of the sulphur in case of accident. These safety pans are best made of thin sheet iron, with the upper edges stiffened by being rolled over wire, and with the sides sloping to allow of nesting.

This simple arrangement was adopted only after considerable experimentation with more elaborate devices, including jackets,

chimneys, and specially shaped pans. These are all subject, in greater or less degree, to the objections that (1) they hinder the free access of air, and hence the flame is taller and more dangerous, and (2) they make the machine unnecessarily complicated, cumbersome, and costly. Moreover, it is found that the back-to-back *en echelon* arrangement of the shelves is all that is necessary to produce an abundance of draft, and in the open-stack burner, properly constructed and loaded, the free access of air on all sides keeps the flame down to a safe height.

OPERATION.

To load the burner or burners, the trays are placed on the floor in a row, long edges touching. Ground¹ sulphur in proper amount is poured into the pans, best from a coal scuttle. The charge is leveled by stroking with the hand and by slight shaking when the pans are being put into the rack. They should be from one to three quarters



Large stack-burner with 15 of the 18 pans removed to show construction.

full. For ignition, the sulphur is well moistened with alcohol, preferably in such a way that the surface shall be quite wet and the deeper layers as dry as possible. This moistening is conveniently done through a finely perforated rose jet, which may be fed through a rubber hose from a large container carried by a sling over the operator's shoulder.²

¹ An unsifted powder (made from the rolls by means of a mill or large mortar) ranging from $\frac{1}{4}$ -inch diameter down, the greater part being quite fine, is the best form of sulphur to use. It pours readily from a bucket, and holds the alcohol near the surface. Sublimed sulphur is nearly as good, and comes ready to use, but is more expensive and is a trifle less convenient to handle and less easy to ignite. Whole or roughly cracked rolls should not be used unless neither the ground nor the sublimed sulphur is available. Nevertheless, the stack-burner will burn the rolls (or any other form of sulphur) much better than will the pot.

² The methods described for the preparation of the sulphur and the application of the alcohol, are also applicable to the lighting of pots, pots so prepared passing to full combustion much more rapidly and certainly than those prepared by the customary methods. Indeed, attention to these details is much more important with the pots than with the stack burner, since the stack burner will burn well under conditions that will result in the failure of the pots.

The pans are then placed in the rack and lighted by a flame. Each shelf should be lighted¹ separately, because while the flames can spread slowly upward from shelf to shelf, the heat, under these conditions, volatilizes much of the alcohol before it ignites and valuable time is lost, the burner generating only slowly at the time when there is but little sulphur dioxide and it should be working at its most rapid rate.

RESULTS.

The ultimate test of any fumigating machine is its power to kill. Bacteriologic tests have not yet been made with our burner, but experiments were made on rats under conditions simulating as nearly as possible the conditions as found in practice, that is to say, the rat was placed in a long, narrow glass cylinder, or a flask with a long neck, communicating by a small opening with the room in which the sulphur was burned. With the open-stack burner, giving a maximum concentration² of about 7.4 per cent, the rats died in 20 to 35 minutes; with the pots, with the best system of charging and the unusually high concentration of 6 per cent, the rat did not die until 115 minutes. In the earlier experiments, in which the pots were charged with cracked roll sulphur in large pieces and the resulting concentration was very low—probably a very frequent result of pot disinfection—rats were not used, but it is believed that they would have had a good chance of survival. This is in accordance with the well-known facts that pot or furnace disinfection of vessels often fails to kill all the rats, and that a considerable number of roaches, etc., almost always escape by hiding in deep and narrow cracks.

Efficiency therefore demands high concentrations rapidly produced.

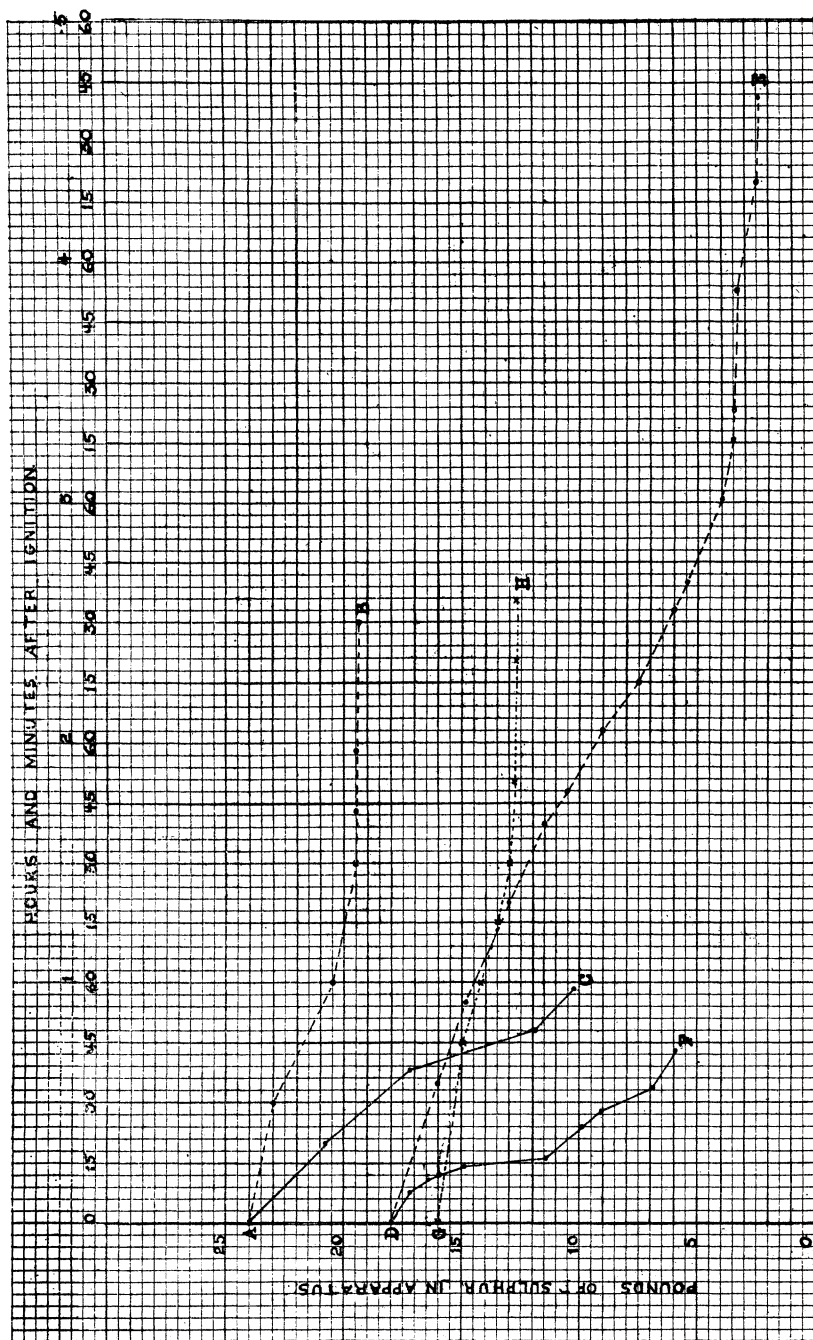
A marked feature of the operation of the stack-burner, as contrasted with the pots, is that the quick combustion of a heavy charge in the stack burner results in a considerable (though not excessive) rise in the temperature of the room, with consequent expansion and forcing of the poisonous gas through every possible outlet, together with a vigorous circulation of the air of the room—hence a marked increase in the penetrating power. In experimenting with the various forms of stack-burner, the experimenters, working in the room next outside of the zinc-lined room in which the combustions were made, were always much inconvenienced and at times driven from the room by the gas which escaped, under evident pressure, in spite of the most careful puttying and pasting of all cracks. When the pots were used and the conditions of increased temperature and pressure prevailed to a less degree, the leakage was much less.

As regards rapidity of combustion and concentration of sulphur dioxide, these are best shown by Charts I and II, respectively. In these the solid lines indicate the results obtained with some form of the stack-burner, while the dotted lines indicate the results obtained

¹ A small gasoline or alcohol blow-torch is probably the best lighter, being portable, powerful, and resistant to draft. A well-charged and primed stack-burner can be ignited in a very few seconds by passing the flame over the faces of the stack, and any shelf that refuses to ignite at once can be vigorously and efficiently assisted by the steady application of the flame for 5 or 10 seconds.

² Of course, the atmosphere of the confined space in which the rat died during a given experiment contained a much lower proportion of SO_2 than the maximum in the large room where the sulphur was burning during that experiment, especially as the rats all died long before the maximum concentration was reached. Nevertheless, in practical disinfection these apparently excessive concentrations are necessary for thorough extermination, because the vermin hide from the sulphur dioxide in the narrowest and deepest holes they can find, and rapidity and depth of penetration (diffusion and convection) of gases is favored by concentration (large difference in percentage composition).

CHART I.—Showing amount and rate of combustion of sulphur in stack-burners (solid lines) and pots (dotted lines).



Curve A-C, stack-burner, 14 pounds out of 24 burned in 1 hour.

Curve D-F, stack-burner, 13 pounds out of 18 burned in 45 minutes.

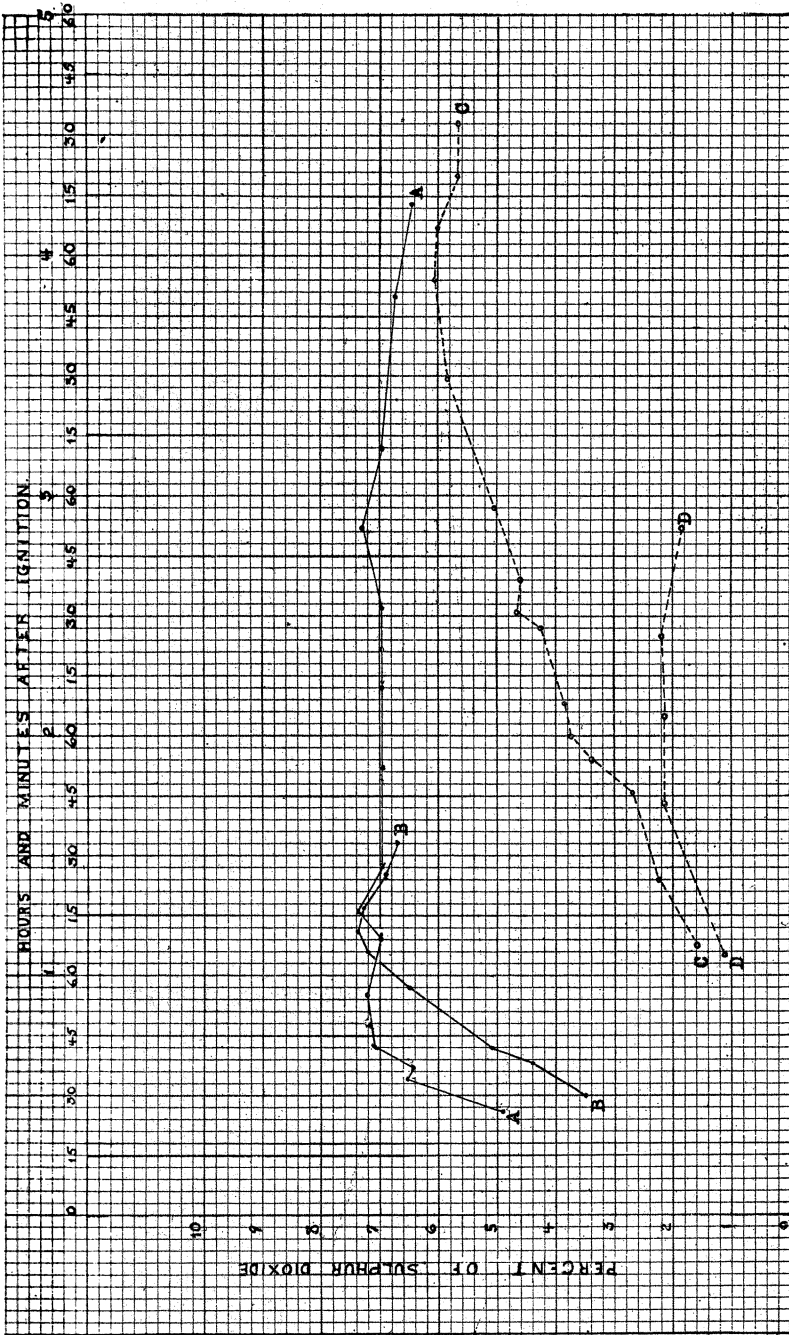
Curve A-B, 3 pots, 4½ pounds out of 24 burned in 2½ hours.

Curve G-H, 2 pots, 3½ pounds out of 16 burned in 2½ hours.

Curve D-E, 2 pots, 15½ pounds out of 18 burned in 4½ hours.

Stack-burners were extinguished abruptly by exhaustion of air; pots died out gradually by cooling and solidification.

CHART II.—Showing percentage of sulphur dioxide in air of room from stack-burners (solid lines) and pots (dotted lines).



Curve A-A, 24 pounds of sulphur ignited in stack-burner.
Curve B-B, 18 pounds of sulphur ignited in stack-burner.

Curve C-C, 18 pounds of sulphur ignited in 2 iron pots.
Curve D-D, 24 pounds of sulphur ignited in 3 iron pots.

with the pots, as noted on the charts. Horizontal distances from left to right indicate time from the moment of ignition; vertical distances upward indicate (in Chart I) the weight of sulphur remaining unburnt, and (in Chart II) the percentage concentration of sulphur dioxide in the air of the room. Thus, of the two lines starting from A in Chart I, A-C represents the loss of weight of a 24-pound charge of sulphur burned in one form of the stack-burner (a pyramidal, jacketed form, with central draft), while A-B represents the loss of weight of a charge of 24 pounds of sulphur burned when equally distributed in 3 iron pots. It will be seen that the pots burned between 4 and 5 pounds in 90 minutes, and then continued to smolder without appreciable loss of weight for an hour more; when the experiment was terminated by opening the room 1 of the pots was still flickering, while the other 2 had gone out.¹ On the other hand, the burner consumed nearly 14 pounds within an hour, the rate of combustion continuing to increase until shortly before the flame was extinguished by the accumulating sulphur dioxide.

The stack-burners will efficiently burn sulphur of too poor quality to give any satisfaction in the pots. In the pot the impurities tend to concentrate on the surface and cut off the feeble heat radiated from above, whereas in the stack the sulphur is rapidly distilled as pure, concentrated vapor by the intense heat from below.² For the same reason the stack-burners, when supplied with enough oxygen, burn the shelves clean of sulphur (except for perhaps a little in some of the corners and a thin glaze in places on the bottom shelf) the impurities remaining as a loose, sulphur-free ash.

If it is desired to charge steam as well as sulphur dioxide into the room, it is easy to substitute water for the sulphur in the top pans, or to support a broad, flat pan of water above, so that the flame will play on it from beneath. This also serves as a baffle and cooler, and hence tends to make the working of the apparatus still safer.³

Neither the pots nor the stack-burners, open or jacketed, have in our experience, given any trouble from "sublimation," the greatest

¹ One of the most exasperating tricks of the pots is their going out when there would seem to be every reason for their staying lighted. This and the better behavior of the stack-burner are, at least in part, explained by the properties of liquid sulphur at different temperatures. Just above the melting point (about 115° C.) sulphur is a transparent, light yellow, very fluid liquid, which (like the solid sulphur) will not burn without the application of considerable heat. As the temperature is raised the liquid becomes darker, more viscid, and more easily ignited, until at (and above) 230° C. ignition in the air is spontaneous. At higher temperatures the sulphur again becomes thinner, and boils at about 450° C. In the stack-burner the temperature of the sulphur rapidly rises to and above the point of spontaneous ignition, and soon the vapor is rapidly forming and burning. In the pot, however, the heat being applied slowly and inefficiently from above, the sulphur melts and passes through the less inflammable stage very slowly, and any slight disturbance (such as motion of the vessel) is apt to throw an excess of the thin, cold liquid or a toppling mass of the solid sulphur into the feeble flame, and to put it out, much as would a dash of water or a shovelful of gravel. The proposal to substitute, for the compact pots, flat pans containing a single broad, shallow layer of sulphur, is not scientific and has been largely ignored by practical men, by reason of the slowness of spread and the ease of extinction of the flame, due to the above-described properties of sulphur.

² To test the open stack-burner to the limit in this particular, it was charged with an intimate mixture of 1 part of ground sulphur and 4 parts of ordinary mortar sand (the sand happening to be somewhat damp), the mixture representing a poor sulphur ore. With a liberal application of alcohol this mixture burned until about two-thirds to three-fourths of the sulphur was consumed. The bottom shelf in this experiment was charged with unmixed sulphur, as the mixture would not burn without heat from below.

³ It is usually stated that if it is desired to disinfect with moist sulphur dioxide enough steam can be generated for the purpose by setting the burning pots in water (warm or cold). No experiments were conducted to determine this point, but any such procedure would be inadequate. Water requires a great deal of heat to evaporate it. It has higher "latent" and "specific" heats than any other common substance, while sulphur liberates relatively but little heat on combustion. In order, therefore, to evaporate any notable amount of water by the burning of sulphur, the water to be evaporated must be held above the flame in a flat shallow vessel of considerable area. On the other hand, the alcohol used in ignition produces on combustion about three-fourths of its weight of water, which may sometimes be seen condensed on the cooler parts of the room and may produce a useful local concentration of the disinfectant.

drawback to the present types of furnace. The probable explanation of this is as follows:

Sulphur in burning gives off much more heat than is necessary to convert it from a solid to a vapor. Therefore a mass of burning sulphur, especially if confined, tends to rise rapidly in temperature until much more sulphur vapor is given off than can be burned at or near the surface of the mass. If this excess of sulphur vapor is discharged into the air immediately or within a short distance (before it cools below the point of ignition) it will ignite spontaneously and burn with a flame; this takes place in the pot and the stack-burner, open or inclosed. But in the furnace the excess of sulphur vapor is shut off from access of oxygen and cooled to condensation during its passage through the long hose. It would seem easy to remedy sublimation in the furnace by a simple modification of the air currents, whereby the air supply would be divided, part going, as at present, to maintain combustion in the boiling liquid, and part to oxidize the excess of sulphur vapor in the escaping gases. Experiments to this end will be undertaken as soon as practicable.

During fumigation the sulphur-dioxide-concentration of the inside air should be determined chemically at frequent intervals. This is a very simple procedure. The air is drawn from the interior by means of an aspirator (suction bottle), the amount of air being measured by the amount of water escaping from the aspirator into a measuring glass. On its way to the aspirator the sulphur-dioxide-charged air is passed through an absorption flask containing 10 cubic centimeters of tenth-normal iodine solution, the flow being stopped at the moment the iodine is decolorized and the amount of water used in aspiration noted. A table (see appendix) gives the percentage concentration corresponding to any given quantity of water. Some such exact method—and this is about the simplest, quickest, and easiest—is the only practicable way to tell how the combustion is progressing and whether the maximum concentration produced is adequate (since even with an altogether inadequate concentration of sulphur dioxide we noted at times a deceptively dense smoke and plenty of smell). This analysis may, moreover, often result in saving much time, since in case the concentration were found only slightly deficient, the deficiency could be quickly made up by liquid sulphur dioxide, whereas it would otherwise be necessary to open and clear the compartment and repeat the whole process *ab initio*, with equally great chances for a second failure.

METHODS OF INVESTIGATION.

The sulphur was burned inside a zinc-lined room, all cracks being closed as tightly as possible. Little leakage occurred except during high winds, or in consequence of increased pressure due to rapid rise of temperature, caused by the rapid combustion in the stack-burner, as mentioned above; but inasmuch as more or less leakage always occurs during fumigation, it is believed that conditions were fairly comparable with those met with in practice.

The loss of weight during combustion was measured by swinging the pots or burners from a wire passing through a cotton-stuffed hole in the ceiling, where it was fastened to a special spring balance above. This balance was provided with a long, light wooden arm, to the end of

which was attached a cord carrying a metal pointer, which indicated against a scale graduated in pounds, located on the wall of the room (next to the zinc room) in which the inside air analyses were made.

The air for analysis was withdrawn through a hole in the wall, the tube inside giving off 3 long branches, extending to the floor, the ceiling, and to a side wall about 5 feet above the floor, respectively. The air in the center of the room was not represented in the analysis, because the animals to be destroyed are crawling rather than winged, and any winged animals soon fall to the floor or alight on the walls. The estimation of the concentration of sulphur dioxide in the air of the room was based on the volume of air necessary to decolorize 10 cubic centimeters of N/10 iodine, as previously described. These estimations were made at intervals during the combustions, being made as rapidly as possible near the time of the maximum concentration. It is evident that any attempt at painful exactness would have been out of place, but all conditions were practically comparable, and the differences noted were so wide that the conclusions are obvious.

APPENDIX.

Table showing the number of cubic centimeters of air (containing the percentage of sulphur dioxide indicated in the last column) required to decolorize 10 cubic centimeters of tenth-normal iodine solution.

[Adapted from Lunge; 0° C. and 760 mm. pressure.]

Volume of water from aspirator= volume of air minus 11.16 cc. (SO ₂). ¹	Volume per cent of sulphur dioxide in air.	Volume of water from aspirator= volume of air minus 11.16 cc. (SO ₂). ¹	Volume per cent of sulphur dioxide in air.
100	10.00	361	3.00
113	9.00	395	2.75
128	8.00	455	2.50
148	7.00	484	2.25
160	6.50	546	2.00
175	6.00	628	1.75
192	5.50	733	1.50
212	5.00	881	1.25
237	4.50	1,105	1.00
268	4.00	1,479	.75
308	3.50	2,221	.50

¹ Ten cc. of tenth-normal iodine is decolorized by 11.16 cc. of SO₂ gas, measured at 0° and 760 mm. (correction for temperature and pressure ordinarily not necessary). The volume of water is less than the volume of aspirated air, because the iodine removes the SO₂—11.16 cc. in each case.